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NASA GUIDANCE AND CONTROL

by

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The National Aeronautics and Space Administration is engaged in an advanced research and technology program, and I will discuss the guidance, control and navigation portions of this program. I shall illustrate the scope of our program by examples.

I would like to emphasize that our guidance and control work is done within a solid electronics framework. Our job in guidance and control is to determine the flight path by navigation means, guide to a flight path, then control and stabilize about this flight path.

The technical areas in which we operate are exemplified by the focal points shown in Figure 1. Deep space guidance is characterized by high accuracy, long life, and reliability required of guidance and control equipment. Attitude stabilization concepts are developed with the aim in mind of living off the environment, wherever possible. Since man is a component in all manned flight vehicles, we concern ourselves with manned flight control and displays. Automatic controls are developed for use both in manned and unmanned vehicles. Specific examples of applications in these technical areas will be given.

A first one is illustrated in Figure 2 by this typical Mars mission in which the very long time of flight illustrates the reliability problem for guidance and control. Here, a spacecraft is orbited around the Earth and, through its electric propulsion, the velocity is increased

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until eventually escape velocity is reached. A midcourse period then carries it to the vicinity of Mars, where it is captured by Mars and by reversed thrust of its electric propulsion it is slowed down, eventually to a landing. The midcourse period is our opportunity to determine and guide to the correct flight path for eventual capture by Mars. Repetitive navigation fixes and guidance corrections during this midcourse period are means of doing this, and error analyses of this mode of operation have shown us the accuracies required for components, such as the inertial sensors shown next in Figure 3.

These inertial sensors are of interest to us because the accuracies, which are reasonable but not extremely high, are suited for this sort of mission, and because of the potentially high reliability.

Figure 4 illustrates a concept of navigation in space. Spacecraft navigation to determine the flight path in space, as contrasted to Earth navigation, requires four angle measurements to determine a fix. One of our more serious problems is in measuring these required angles from a spacecraft. Many of the subsystems in a spacecraft, including man himself, contribute to the disturbances aboard the spacecraft, and the pointing of the entire spacecraft in order to point the very accurate optical instruments required for measuring the navigation angles, because of these disturbances, is difficult and uses excess fuel. One of our proposed solutions is to use a very carefully inertially stabilized, separately oriented, platform for making the optical measurement. This "dog on a leash" to the spacecraft, the leash containing information in and out as well as power, and with the spacecraft guiding roughly on the dog, appears to be a very promising approach to a very carefully

stabilized navigation instrument. In addition, this stabilized platform appears to be potentially useful for pointing a laser for space work.

Figure 5 illustrates one means used for the determination of the vertical and for determining altitude horizon scanning. In the case of the Earth at least, and I think this will be true in the case of other planets, we do not really know how to define the horizon. We are lacking basic experimental data.

Project Scanner will send up a space probe containing optical and infrared sensors to gather the basic horizon information. From this data, which will be available in 1964, we will be able to specify and design adequate horizon-sensing devices for spacecraft.

For attitude stabilization and control, shown in Figure 6, we would prefer to use passive devices, living off the environment. We find ourselves, however, not always able to use these so that we are continuing to work on active devices: control jets and momentum exchange devices. We are working on a reaction sphere where one sphere replaces three flywheels. Passive devices considered for Earth orbital use include utilizing two effects, gravity gradient, which provides a naturally occurring restoring force on any unsymmetrical space vehicle, and the reaction of a local magnet with the Earth's magnetic field. One of our greatest problems in utilizing these naturally occurring forces is that no inherent damping forces are available in space. We have utilized magnetic damping for this purpose, and other means have been proposed. One other scheme is to use a solar sail as an anchor, in this case to leeward, pointing out behind the spacecraft away from the sun, against which friction devices for damping can be operated.

For manned control systems, for both space and aeronautics, we are developing displays and controls and doing related psychological work, performance measures, and human engineering. The display indicated in Figure 7 is typical of some of the display work, an outgrowth of the X-15 program. An entry corridor for a reentering space vehicle determines an area on the ground available to the pilot for landing, which is displayed. By a map overlay, specific air fields can be selected for landing. Old aviators will recognize this as trading altitude for air speed.

Development of displays and controls of this sort requires ground simulation. The facility represented in Figure 8 is typical of the simulator efforts now going on. This is an Ames Research Center simulator, soon to be built, in which the crew, and controls and displays are placed in a cab which can be rotated on a centrifuge with five degrees of freedom. A complete space mission can be simulated in this sort of environment, and verification of theories developed earlier occurs here. From this verification then, design criteria and design data are generated.

Figure 9 represents the diverse nature of vehicle control research. Automatic control research on vehicles tends to concentrate on faster speeds, increased thrust and wind loads of new vehicles. We have great problems in the control business with correcting for vehicle structural flexibility. The big boosters really bend. And, of course, the need for reliability remains with us.

Our efforts in the automatic control theory area are primarily towards applying the theories that now exist. We are faced with the situation of having a large body of potentially very useful automatic control theory.

Design engineers are not using this theory for one reason or another and our aim then is to get the theoretical work in such form that the design engineers can use it.

I hope this overview of some of our work gives a better picture of the aeronautical and space guidance and control advanced research now in progress and planned. Our aim is to have an advanced technology available for the use of future projects as their needs demand.